Containment Sprays (SPR) Package Reference Manual

The Containment Sprays (SPR) package models the heat and mass transfer between spray water droplets and the containment building atmosphere. The SPR package models were extracted from the HECTR 1.5 code.

This reference manual describes the models employed in the SPR package. Detailed descriptions of the user input requirements can be found in the SPR Package Users' Guide.

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1. Introduction

Where possible, MELCOR uses a generic building-block approach to modeling engineered safety features (ESFs) through use of control volumes, flow paths, heat structures, and control functions. However, for containment sprays, separate models tailored to this system have been implemented in MELCOR.

The MELCOR Containment Sprays (SPR) package models the heat and mass transfer resulting from operation of containment spray systems. The removal of fission product vapors and aerosols by ESFs is modeled within the RadioNuclide (RN) package. See the RN Package Reference Manual for details on this modeling.

2. Model Description

The Containment Sprays (SPR) package models the heat and mass transfer between spray droplets and the containment building atmosphere. The modeling in the SPR package was taken virtually intact from the HECTR 1.5 code [1], following the recommendations of the MELCOR phenomena assessment on modeling containment spray systems [2]. The model assumes, among other things, that spray droplets are spherical and isothermal and that they fall through containment atmospheres at their terminal velocity with no horizontal velocity components.

An arbitrary number of spray sources may be placed at various heights in any containment control volume. The source of water for each spray may be associated with the pool in any CVH control volume or it may be left unspecified. If a CVH pool is specified as the spray source reservoir, then input (“dryout” pool depth) may be specified to determine whether there is sufficient water in the pool to permit spray operation. Input (resumption pool depth) may also be specified to determine when spray operation may resume following “dryout”. If the pool depth for spray source resumption exceeds the pool depth for spray source “dryout”, then there will be hysteresis in the spray operation curve that will prevent excessive cycling between episodes of spray operation. In a special application, the spray model also receives water from the Heat Structures (HS) package film-tracking model whenever rain from inverted HS surfaces enters the containment atmosphere.

For each spray source, except for sources associated with rain from the HS film-tracking model, the user must specify an initial droplet temperature and flow rate, each of which may be controlled by a control function. The user may turn the sprays on and off with a separate control function for each spray source. A droplet size distribution also may be input for each spray source. In other words, the spray droplets for each source may be divided into a number of different size bins, with individual drops representing the average droplet size being tracked during their fall through the control volume; the total heat and mass transfer for the spray source is obtained by summing the heat and mass transfer calculated for each size.

For each droplet type in each control volume, the following differential equations are solved to determine the heat and mass transfer rates and the terminal fall velocity as a function of drop size:

$$\frac{dm}{dt} = -2\pi\ \rho_g D\left(1 + 0.25\mathrm{Re}^{1/2}\ Sc^{1/3}\right) D_c \ln(1 + B) \tag{2.1}$$

$$\frac{dT}{dt} = \frac{1}{m\ c_{pl}}\left[\frac{c_{pv}\left(T - T_{cv}\right)}{(1 + B)^{1/Le} - 1} + h_{fg}\right]\frac{dm}{dt} \tag{2.2}$$

$$\frac{dz}{dt} = \left[\frac{4\left(\rho_d - \rho_g\right)g\ D}{3\rho_g C_d}\right]^{1/2} \tag{2.3}$$

In these equations, the terms are defined as

m	= droplet mass,
T, T_{cv}	= droplet, control volume atmosphere temperatures,
z	= droplet fall height,
ρ_d, ρ_g	= droplet, atmosphere densities,
c_{pl}	= droplet specific heat capacity,
c_{pv}	= control volume atmosphere specific heat capacity,
h_{fg}	= latent heat of vaporization,
D	= droplet diameter,
Re	= Reynolds number,
Sc	= Schmidt number,
Le	= Lewis number,
D_c	= diffusion coefficient,
C_d	= drag coefficient,

and B is the mass transfer driving force

$$B = \frac{x_b - x_i}{x_i - 1} \tag{2.4}$$

where x_b and x_i are H_2O mass fractions in the bulk atmosphere and at the liquid-gas interface (corresponding to saturation). Equations (2.1) through (2.4) are based on forced convection heat transfer and evaporation and condensation correlations that have been formulated specifically for high temperature atmospheres, such as might be encountered during a hydrogen burn [3]. The constants in Equation (2.1) have been implemented in sensitivity coefficient array 3001.

Correlations for the drag coefficient of spheres, C_d, are used for the following Reynolds number regimes, with the various constants implemented in sensitivity coefficient array 3000:

$$c_d = 27\,\mathrm{Re}^{-0.84} \qquad \text{for Re < 78} \tag{2.5}$$

$$c_d = 0.271\mathrm{Re}^{0.217} \qquad \text{for 78 < Re < 10000} \tag{2.6}$$

$$c_d = 2 \qquad \text{for 10,000 < Re} \tag{2.7}$$

The transfer rates given by Equations (2.1) through (2.3) are integrated by a Runge-Kutta method over the fall height of the spray droplet to obtain the final droplet mass and temperature. By comparing the droplet mass and temperature at the bottom of the compartment to the inlet conditions, the heat transfer and mass transfer to a given droplet are computed. Total heat and mass transfer rates are calculated by multiplying the rates for one droplet by the total number of droplets of that size and summing over all droplet sizes. It is assumed that this total heat and mass transfer rate is constant over a given timestep, and it is also assumed that the containment atmosphere conditions do not change significantly during the fall time of the drop.

The user can describe how droplets falling from one control volume are to be carried over to lower volumes. A control volume may be designated as the containment spray sump. Droplets leaving designated control volumes and not carried over to other volumes will be placed in the pool of the sump. Droplets reaching the bottom of a control volume and not being carried over to other volumes or placed in the sump are put into the pool of the control volume.

It should be noted that the SPR package does not model interactions between spray droplets and other structures (nor does any other MELCOR package). Thus, it is not possible to model either core sprays or steam generator auxiliary feed water sprays properly using the SPR package.

The SPR package is coupled to the RadioNuclide (RN) package for the calculation of aerosol washout and atmosphere decontamination by the sprays. Current limitations of this interface require some restrictions on the input to the SPR package to avoid nonphysical results associated with multiple calculations in the same control volume. When the SPR and RN packages are both active, the user should limit the spray input so that only one spray train passes through each control volume and only a single drop size is used in this spray train.

References

1. S. E. Dingman, A. L. Camp, C. C. Wong, D. B. King, and R. D. Gasser, HECTR Version 1.5 User's Manual, NUREG/CR-4507, SAND86-0101, Sandia National Laboratories, Albuquerque, NM (February 1986).

2. G. G. Weigand, ed., Thermal-Hydraulic Process Modeling in Risk Analysis: An Assessment of the Relevant Systems, Structures, and Phenomena, SAND84-1219, NUREG/CR-3986, Sandia National Laboratories, Albuquerque, NM (August 1984).

3. F. A. Williams, Combustion Theory, Addison-Wesley, Reading, MA (1965).